Unlicensed TV White Space Wireless Cannot Provide Substantial Rural Broadband Access

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Introduction and Summary

The proponents of unlicensed use of the TV white space have repeatedly claimed that rural broadband access is an unmet need that can be served by the TV white space. Last June, the New America Foundation released a paper entirely devoted to touting the benefits of unlicensed use of the TV white space for rural broadband access.[1] In that paper, they asserted,

> The best way to ensure that the TV "white spaces" boost rural broadband is free, shared, unlicensed access. Unlicensed access would provide local users, governments, commercial WISPs and RLECs with the ability to determine the best uses for the spectrum resources in their geographic area.

Last week, two congressional offices issued releases praising FCC Chairman Martin's proposal to permit unlicensed use of the TV white space. One release spoke of "providing low-cost wireless broadband service to Americans in rural areas."[2]

Unfortunately, those who suggest that unlicensed use of the TV white space will support rural broadband access have not provided any engineering or economic analysis to support their assertions. They have provided some vague statements that the UHF frequencies of the TV band permit wireless signals to travel farther than is the case in the other unlicensed bands. For example, the New America Foundation study referenced above asserts, "Signals in the TV band travel far greater distances at lower power and are far less susceptible to physical obstructions by trees, hills and buildings."

It is true that, under some reasonable technical assumptions and all other things being equal, signals in the TV band can provide better coverage than signals in the unlicensed band at 2.4 GHz or in the PCS band at 1.9 GHz.[3] But, all other things are not equal. In particular, the proposed rules for unlicensed use of the TV white space restrict those

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[1] "Rural Broadband and the TV White Space: How Unlicensed Access to Vacant Television Channels Can Bring Affordable Wireless Broadband to Rural America," by Benjamin Lennett, New American Foundation, Issue Brief 22 June 2008.

[2] "Martin: FCC Concludes White spaces Devices Can Share DTV Spectrum," John Eggerton, *Broadcasting & Cable,* 15 October 2008.

[3] Radio signal coverage is a complex topic, and no one- or two-sentence rule of thumb can adequately summarize the relevant science. In fact, in many reasonable situations, a signal in the 2.4-GHz unlicensed band would provide better coverage or more capacity than would an equal power signal in the TV band.

unlicensed devices to powers far lower than are permitted for licensed services. That higher power for the licensed service more than makes up for the somewhat superior radio signal propagation of the UHF TV band.

Perhaps an analogy or two will show how more of one resource can compensate for lack of another resource. Consider skill and ability versus numbers. It is probably the case that the Redskins would handily defeat the University of Maryland in a football game—the Redskin players are more experienced both as individuals and as a team, and the Redskin players are, on average, better football players than the Maryland players. However, if Maryland were allowed to have 22 players on the field at all times while the Redskins were restricted to the traditional 11 players, it seems overwhelmingly likely that Maryland would win. On defense, Maryland could rush 10 players, keep 6 players on the line, and have 6 players in deep pass coverage; on offense, Maryland could put 2 or 3 blockers on every rusher.

Similarly, consider skill versus power. If you put an average driver in a NASCAR racer and you put Jimmy Johnson, current leader in the NASCAR standings, in a similar vehicle, Johnson would handily defeat the other driver in a race on a NASCAR track. However, if you restricted Johnson's car to 4 horsepower, the average driver—with skills far inferior to Johnson's but driving a car with more than 700 horsepower—would easily win a race.

In the two following sections, I describe some engineering calculations I made to compare the wireless coverage of unlicensed TV white space devices operating under the technical rules that FCC Chairman Martin described in his October 15 news conference and under those contained in the FCC's proposed rules for unlicensed operation in the white space with the wireless coverage of licensed operations under the current FCC rules that govern licensed wireless spectrum. The bottom line of that analysis is shown in Figure 1, which compares the coverage that could be provided by an unlicensed TV white space base station and the coverage that could be provided by a licensed service provider operating on a nearby frequency, but using the technical rules that apply in the recently auctioned 700-MHz band.

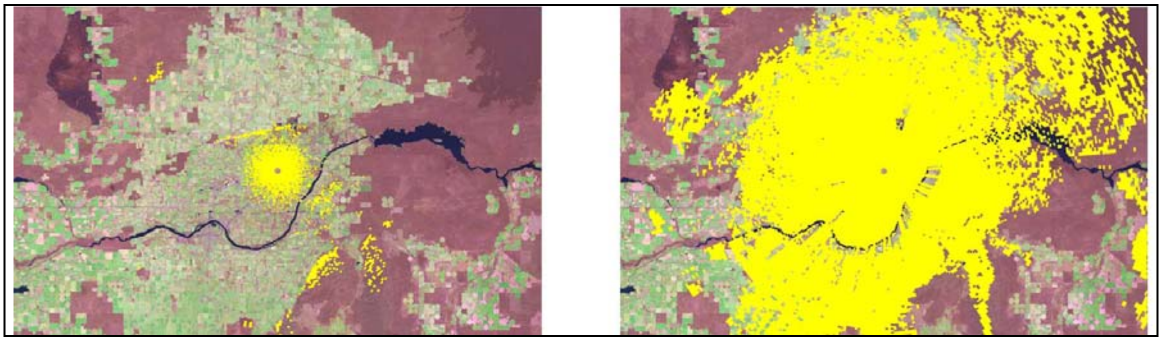

Figure 1. Left Panel: Unlicensed TV White Space Station Coverage.
Right Panel: Licensed Service Provider Coverage.

The coverage that would be provided by a 4-watt transmitter, the maximum power that is proposed for unlicensed operation, is shown on the left. It covers Rupert, Idaho—the county seat of rural Minidoka County—but does not cover the farms in the county. The coverage that would be provided by a transmitter with all other parameters the same except that it would have 1000 times more power, 4 kilowatts, and would operate in the recently auctioned 700-MHz band is shown on the right.[4] That signal covers most of the farms in Minidoka County and many of the farms in Cassia County to the south. It also covers the nearby towns of Heyburn, Burley, Declo, and Minidoka. In total, it covers about 20 times the area covered by the unlicensed base station.[5]

[4] The specific technical parameters for this comparison are given in Appendix B. The 4-kW power for the licensed transmitter may seem high to some. However, Part 27 of the FCC rules permits operation at powers well above this level in the recently auctioned 700-MHz bands in rural counties such as Minidoka. With the use of directional antennas, the total transmitter power would only need to be about 200 to 400 watts.

[5] I believe that this paper's primary conclusion—that unlicensed use of the TV white space cannot provide significant rural broadband access—is straightforward and should be uncontroversial. The technologist's reaction to claims that low-power, unlicensed devices can really be used for rural broadband access was illustrated by a technical reviewer of this paper. That engineer—an individual unfamiliar with the TV white spaces debate—wrote, "When I was reading [a draft of this report] I thought maybe [Jackson] and/or I had missed the point entirely. *Is anyone seriously considering setting up 4 watt service areas to deliver rural broadband access*?"

Comparing Licensed and Unlicensed Coverage in a Specific Rural Market

Minidoka County in southern Idaho is a predominantly rural county with about half of the land area being farmed. The non-farmed areas include lava beds and a national wildlife refuge. Appendix A provides details on the demographics and topography of Minidoka County. I used a software tool named *Radio Mobile* to generate coverage plots for hypothetical wireless systems serving Minidoka County. *Radio Mobile* uses the NTIA Irregular Terrain Model (ITM) to predict radio coverage; that model is also known as the Longley-Rice Model and is used by the FCC for a variety of purposes.[6] *Radio Mobile* uses a digital geographic data base along with information about the transmitting and receiving systems to calculate the strength of a received signal at any location.

Figure 2 shows the coverage from an unlicensed base station operating in Rupert at the maximum power that the FCC proposes to allow for such unlicensed fixed stations—a power well above that which Chairman Martin suggested would be possible for the unlicensed mobile devices.[7]

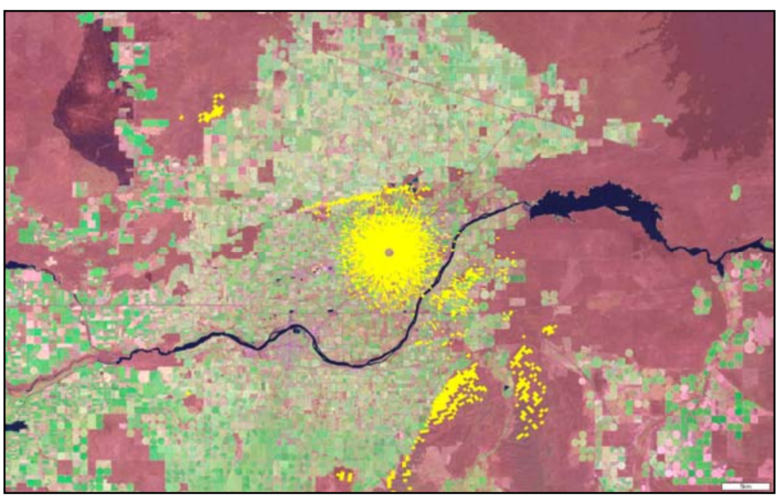

Figure 2. Coverage of Unlicensed System 600 MHz, 4 W, 30 Meters above Ground

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6 For example, FCC Bulletin OET-69 describes how to calculate DTV coverage using the Longley-Rice Model.

7 See Appendix B for the specific modeling assumptions used to generate the coverage maps.

The town of Rupert itself gets coverage, but there is little coverage outside of town. Few farms get service. A total of 110 square kilometers (about 40 square miles) is predicted to receive an acceptable signal.

Figure 3 shows the dramatically larger predicted coverage area from a licensed base station operating in the 700-MHz band with the same technical parameters as the unlicensed system in Figure 2 except it is operating at 4,000 watts—one-third of the maximum permitted power.[8] A licensed system operating in the TV white space under rules similar to the current FCC rules for 700 MHz would have essentially the same coverage.

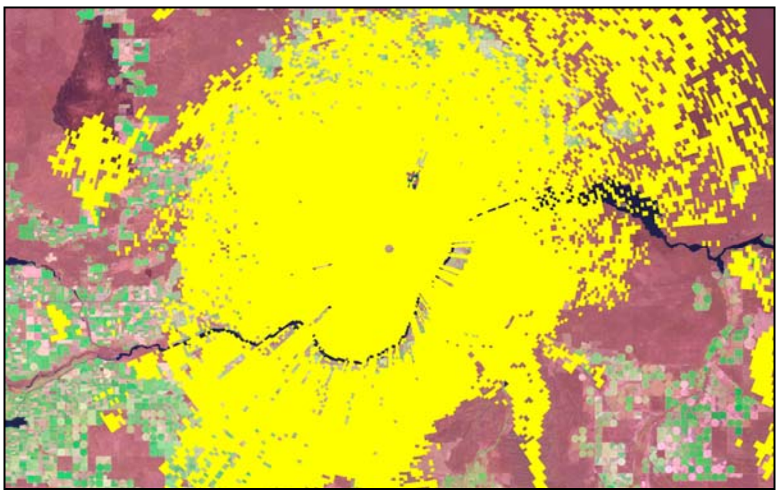

Figure 3. Coverage of Licensed System 750 MHz, 4 kW, 30 Meters above Ground

Most of the farms north of the Snake River get coverage, as do many farms in Cassia County south of the river. Total coverage in this case is 1,988 square kilometers—20 times more coverage than is predicted for the unlicensed service.

Another analyst might choose different values for some of the parameters in this analysis. However, the key difference is the higher power permitted licensed operators. The analysis here is apples-to-apples—the only variables being changed in the computer

[8] The FCC rules impose of power limit in Minidoka County of 2 kW/MHz or 12 kW/6MHz. See 27.50(c)(4). I use 4 kW, one-third of the maximum permitted power, for simplicity.

model are the power and the frequency. The radio propagation model parameters and the geography are unchanged. The relative difference between the outcomes should persist for a wide range of the parameters that are not changed. Similarly, there is nothing special about Rupert and Minidoka County; similar disparities should be found in most rural areas.[9]

Figure 4 shows the predicted coverage from a system operating in the PCS band but otherwise similar to the system of Figure 3.

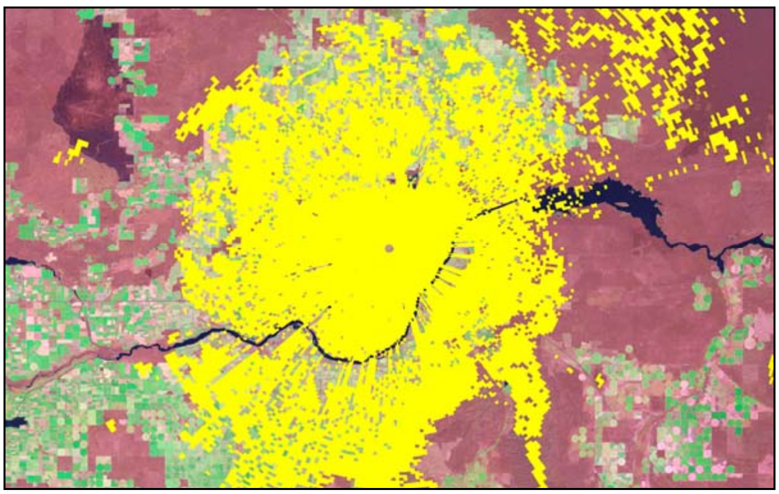

Figure 4. Coverage of Licensed System 1960 MHz, 4 kW, 30 Meters above Ground

Comparing this figure with Figure 3 shows the nature of the so-called "beach front" advantage of the UHF frequencies of the TV white space. There has been a notable shrinkage in the coverage, but coverage has not collapsed. The coverage gaps along the south side of the river have expanded, and there are other holes in the coverage. The area covered has fallen by about 30% to 1,360 square kilometers. Nevertheless, the coverage of the high-power PCS signal is far better than the coverage provided by the weak signal from an unlicensed device in the TV white space. Any firm that wished to provide wireless broadband access to the farms in Minidoka County using TV white space

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9 The only situation in which the low-power unlicensed service and a higher-power licensed service would provide similar geographic coverage would be for a community in a steep, twisting valley where hillsides would block the signal in every direction.

devices would face the threat of competition from wireless carriers using licensed frequencies with far better coverage and lower costs because fewer base stations would be needed. And, that is not a hypothetical threat by any means. At least two commercial carriers (Verizon Wireless and Sprint) provide wireless broadband service throughout Minidoka County via the EV-DO technology on licensed spectrum.

Better coverage in the licensed services does not require powers as high as 4 kW. Figure 5 shows the coverage in the PCS band if power is reduced to 400 watts.

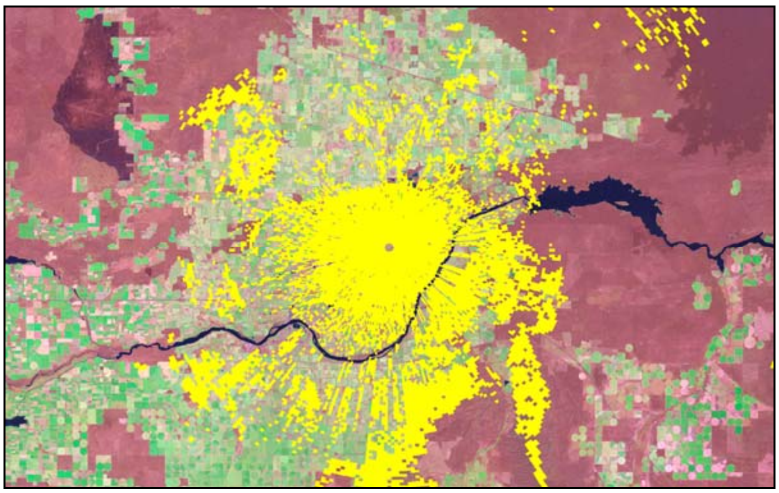

Figure 5. Coverage of Licensed System 1960 MHz, 400 W, 30 Meters above Ground

Coverage has now shrunk to 656 square kilometers. But the coverage is still markedly better than the coverage from the unlicensed base station in the TV white space. The 100-times higher power in the PCS band more than overcomes the difference between radio wave propagation in the PCS band and the UHF TV band.

This analysis has focused on the base-to-subscriber radio link. An analysis could also be performed on the subscriber-to-base link. The results would be somewhat similar, but the difference between the unlicensed system and the licensed system would be less striking. Chairman Martin's press conference statements indicated that mobile subscriber devices would be permitted to transmit at powers as high as 0.1 watts. Typical subscriber devices for licensed wireless services usually have the capability to transmit at higher powers, often as high as 1 watt—so there is only a 10:1 disparity in uplink power. However, because Internet access involves much more downlink than uplink traffic, the disparity in downlink capacity controls system performance.

All of this analysis leads to the unsurprising conclusion that much more power can make up for slightly unfavorable properties of the bands above the TV band. Just as we would expect Maryland with 22 players on the field to beat the Redskins, licensed services that are permitted to use powers as much as three thousand times stronger than the FCC proposes allowing unlicensed devices in the TV white space would outperform the unlicensed devices—even if they were to operate in portions of the radio spectrum with slightly less favorable signal propagation.

Wireless Local Area Network Coverage and Capacity

One well-known use of unlicensed wireless is for wireless local area networks (WLANs), with Wi-Fi being the best known example of this technology. A quick calculation shows that unlicensed devices in the TV white space would be inferior to devices in the 2.4- and 5-GHz unlicensed band for WLAN applications. At short ranges, such as inside the house, signals do not attenuate much between the transmitter and the receiver, and the received power is relatively high. In such high-power situations, the capacity of the wireless link is determined more by the bandwidth of the link than by the power. The TV white space comes in 6-MHz TV channels, and it appears highly likely that unlicensed TV white space devices would operate in 6-MHz channels. Devices operating in the 2.4- and 5-GHz unlicensed bands can use much larger bandwidths. Wi-Fi traditionally has used a 20-MHz channel and now has an option for using a 40-MHz channel. Below is a graph showing the capacity in bits-per-second of a 6-MHz link in the TV white space and of a 40-MHz link in the 2.4-GHz band as the distance between the transmitter and receiver varies. It was calculated assuming equal powers of 0.1 watts, free-space propagation, a receiver with a 10-dB noise figure, and the Shannon capacity formula for additive white Gaussian noise.

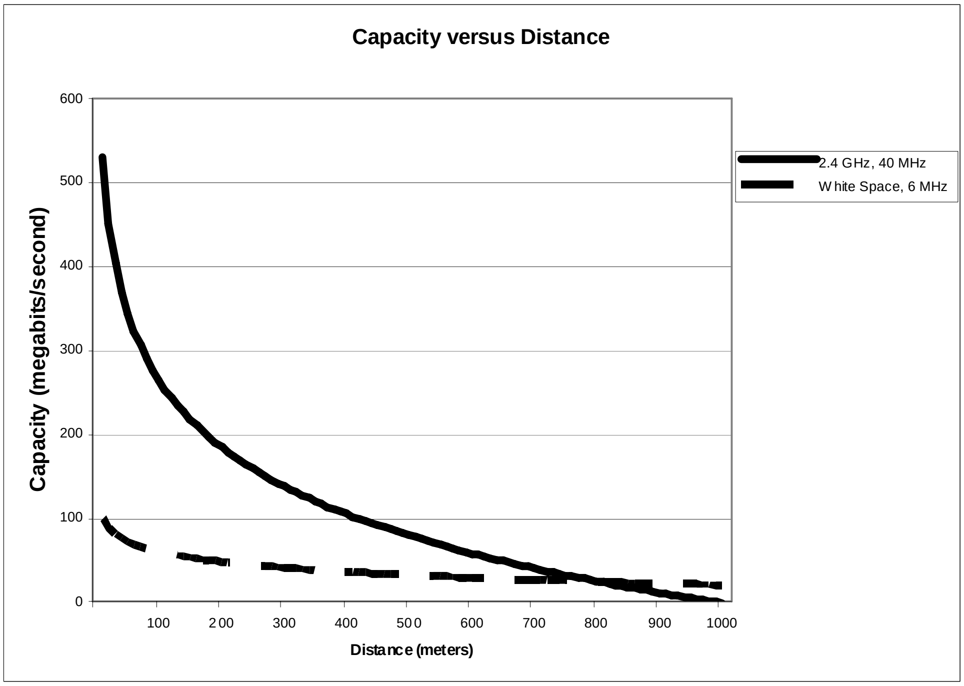

Figure 6. Comparison of the Shannon Capacity of a 6-MHz-wide White-Space Link and a 40-MHz-wide 2.4 GHz Link

The additional bandwidth at 2.4 GHz more than makes up for the reduced free-space loss at the UHF TV frequencies at all close-in distances. This comparison is illustrative and omits many features that are important in the real world. For example, multiple-input, multiple-output (MIMO) technology works better at 2.4 GHz than at the UHF TV band, but signals in the UHF TV band penetrate walls better than do frequencies at 2.4 GHz. However the general proposition is undeniable—at short ranges, the greater bandwidth available at 2.4 and 5 GHz permits far higher data rates.

Conclusions

Licensed wireless systems operate at far higher powers than is proposed for unlicensed devices that would operate in the TV white space. Consequently, the licensed wireless carriers can provide far better coverage from their base stations than can a base station using an unlicensed TV white space device, and licensed wireless carriers would have a substantial cost advantage over service providers that choose to provide service using unlicensed TV white space devices. This cost advantage means that operators choosing to use unlicensed TV white space devices to provide broadband access would always face the threat of a licensed firm coming in and offering a better, lower-cost service. This threat would discourage investment. And, if the current, licensed wireless firms have not yet chosen to build out to serve a region, why would another firm be willing to do so using an inferior technology? It is hard to think of any scenario in which unlicensed use of the TV white space under the proposed rules can or will provide broadband access to a significant number of rural households.

Unlicensed devices are also handicapped when used for short-range services. The natural bandwidth limitation to 6-MHz channels in the TV white space means that unlicensed TV white space devices would have substantially less capacity for short-range communications such as within a home or office. Consequently, there would only be weak incentives for firms to bring to market products such as WLANs operating in the TV white space.

The best applications for unlicensed TV white space devices are those requiring relative low bit-rates and longer range—but not range so long that the application is better served by licensed services. This is a small niche. Given that unlicensed TV white space devices would be inferior to existing alternatives for both short-range and long-range applications, it would be more efficient to make the TV white space available for licensed use under rules that would permit the economic provision of long-range services.

Appendix A: Minidoka County, Idaho

The county has a land area of 736 square miles and a population of 19,014, with 6,973 households. The population density is 25 persons per square mile—well below the FCC's rural definition of 100 persons per square mile.[10] To put this in perspective, Montgomery County, Maryland, is about the same size—30% smaller actually—but has a population of 873,341 people, giving the county a population density of 1,700 people per square mile. The county seat and largest city in the county is Rupert, with a population of 5,645. The county has only four public elementary schools—a fact that illuminates some of the differences in lifestyle between this county and more densely populated regions. The land area of the county is relatively level.[11] Figure A-1 shows a satellite image of the southern Minidoka County area along with part of Cassia County to the south. The region shown is approximately 50 km (30 miles) from top to bottom and 80 km (50 miles) from side to side.

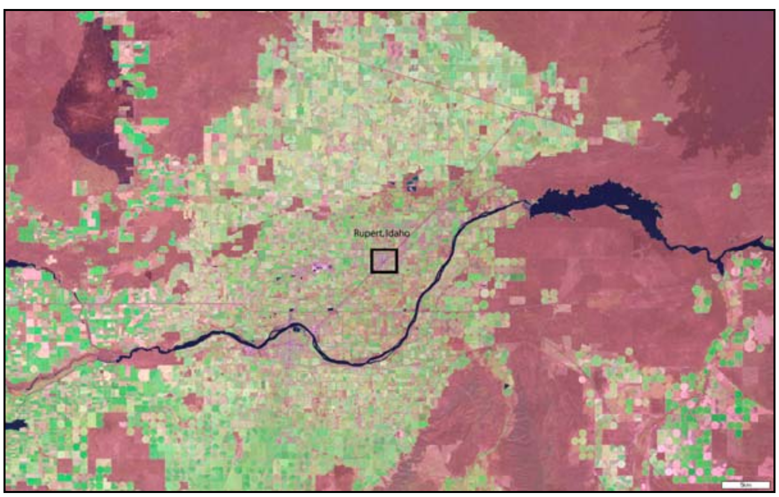

Figure A-1. Satellite Picture of Rupert, Idaho, and Vicinity

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[10] See 47 CFR 27.50, which uses 100 persons per square mile in a county as the cutoff for permitting higher base station power.

[11] For information on Minidoka County see the county's website http://www.minidoka.id.us/index.htm or the Wikipedia article http://en.wikipedia.org/wiki/Minidoka_County.

The dark, wavy line running from right to left across the figure is the Snake River, which forms the southern county line. The many round circles are large fields with center-pivot irrigation systems.

Figure A-2 is a color topographic map of the same area as in Figure A-1.

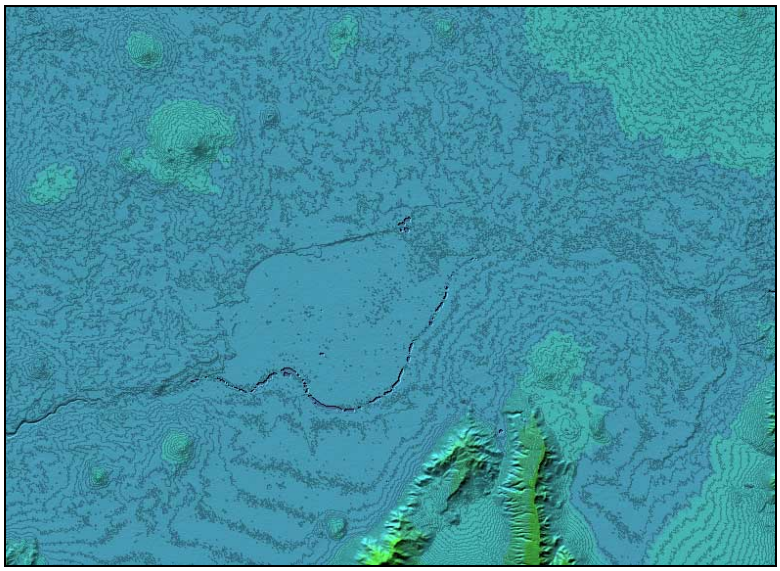

Figure A-2. Topographic Map of Rupert, Idaho, and Vicinity

Appendix B: Modeling Assumptions

All coverage maps were calculated using *Radio Mobile.*[12] The terrain database used is the one arc-second SRTM data. For information on that data, see the *Shuttle Radar Topography Mission (SRTM) Technical Guide* available at http://www.landcover.org/data/guide/technical/techguide_srtm.pdf. The coverage results are displayed over a Landsat photo of the region. Comparison of plots of the terrain database with the photo image shows that the river and other prominent geographical figures are correctly aligned in the two images. Thus, we can be confident that the calculated coverage is properly shown on the satellite photo.

In all cases, the geographic region shown is that between north latitude 42-24-04 and 42-51-03 and between west longitude 113-10-35 and 113-10-53.

The ITM parameters used are as follows:

> Mobile mode of variability, 50% time and 70% situations,
> Desert climate,
> Surface refractivity 301,
> Ground conductivity 0.005,
> Relative ground permittivity 15, and
> Vertical polarization.

The surface refractivity, ground conductivity, and ground permittivity used here are the same as are specified by the FCC in OET-69.

The various systems shown in Figures 2–5 were modeled with the data specified above, together with the figure-specific assumptions or input data given in the tables below. (Figure 1 is a combination of Figures 2 and 3.) Some of the tables below are followed by a discussion of the parameters used in those tables that explains how specific parameter

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12 Documentation for this package is available at http://www.cplus.org/rmw/english1.html.

values were chosen or how parameter values relate to the proposed rules for unlicensed operation in the TV white space, to wireless industry practice, or to the FCC rules.

Table B-1. Radio System Parameters for Figure 2

Frequency	600 MHz
Transmit EIRP	4 W
Transmitter Antenna Height	30 m (about 100 feet)
Transmitter Antenna Location	42.63597 E, 113.6655 W
Receiver Antenna Height	1.5 m (about 5 feet)
Receiver Antenna Gain (dBi)	0
Building Penetration Loss	15 dB
Definition of Coverage	Received signal greater than −95 dBm

In Table B-1, the frequency 600 MHz was chosen for the representative unlicensed TV white space device because that is approximately the middle of the (posttransition) UHF TV band. The power of 4 watts is the maximum power that the FCC proposes to permit in the TV white space. The base-station antenna height of 30 meters was chosen because it represents a tower sufficiently high to provide good service but not so high as to be extraordinarily expensive. A 10-story building is about 30 meters high. I believe that there are no buildings higher than about three stories in Rupert, Idaho, so the signal from a 30-meter tower would not be blocked by buildings in the center of town. A signal of −95 dBm is strong enough to provide good service. The building penetration loss of 15 dB is really a surrogate for all excess losses, including building penetration, antenna efficiency, polarization mismatch, and body absorption. The receiving antenna height of 1.5 meters is often used to model personal wireless receiver antenna height.

Table B-2. Radio System Parameters for Figure 3

Frequency	750 MHz
Transmit EIRP	4 kW
Transmitter Antenna Height	30 m (about 100 feet)
Transmitter Antenna Location	42.63597 E, 113.6655 W
Receiver Antenna Height	1.5 m (about 5 feet)
Receiver Antenna Gain (dBi)	0
Building Penetration Loss	15 dB
Definition of Coverage	Received signal greater than −95 dBm

Table B-2 is identical to Table B-1 except for two changes. The frequency has been changed to 750 MHz, the middle of the 700 MHz band that was recently auctioned, and the power has been increased to 4 kW (4,000 watts). FCC rules set a base station power limit for the 700 MHz band of 2 kW/MHz in rural areas such as Minidoka County or 12 kW for a 6 MHz channel, so this power, although 1,000 times greater than the power permitted the unlicensed system, is only one-third of the maximum permitted.[13]

Table B-3. Radio System Parameters for Figure 4

Frequency	1960 MHz
Transmit EIRP	4 kW
Transmitter Antenna Height	30 m (about 100 feet)
Transmitter Antenna Location	42.63597 E, 113.6655 W
Receiver Antenna Height	1.5 m (about 5 feet)
Receiver Antenna Gain (dBi)	0
Building Penetration Loss	15 dB
Definition of Coverage	Received signal greater than −95 dBm

[13] 47 CFR 27.50.

The parameters used in creating Table B-3 are the same as for Table B-2 except the operating frequency has been changed to 1960 MHz, which is the middle of the PCS base-to-mobile band.

Table B-4. Radio System Parameters for Figure 5

Frequency	1960 MHz
Transmit EIRP	400 W
Transmitter Antenna Height	30 m (about 100 feet)
Transmitter Antenna Location	42.63597 E, 113.6655 W
Receiver Antenna Height	1.5 m (about 5 feet)
Receiver Antenna Gain (dBi)	0
Building Penetration Loss	15 dB
Definition of Coverage	Received signal greater than −95 dBm

Table B-4 is identical to Table B-3 except that the power has been lowered to 400 watts.